Rich Legacy from Atoms for Peace

Livermore researchers have applied their nuclear weapons expertise to develop technologies for civilian uses.

ON December 8, 1953, in an address to the United Nations General Assembly, President Dwight D. Eisenhower called upon all world leaders to move toward peaceful rather than destructive uses of nuclear technology. He said that nuclear technology "must be put into the hands of those who will know how to strip its military casing and adapt it to the arts of peace." This historic address, afterward referred to as the Atoms for Peace speech, sparked a significant research and development effort to apply nuclear technology for civilian use.

In 2003, Livermore's Center for Global Security Research (CGSR) commemorated the 50th anniversary of Eisenhower's speech by conducting a series of workshops to discuss the progress made toward the goals he outlined. (See the box on p. 8.) CGSR deputy director Eileen Vergino notes that the influence of Eisenhower's initiative can be seen in many areas. "Technologies developed in nuclear weapons programs have been applied to medical diagnostics and treatments, detectors, research tools, and power generation. Research initiatives following the spirit of Atoms for Peace also brought us the technologies needed to build confidence in the arms-control treaties that furthered détente with the Soviet Union."

At the time of Eisenhower's speech, the world was experiencing dynamic and precarious changes. China had fallen to communism; Stalin, who had consolidated the Soviet empire in Eastern Europe, had died; and the U.S. was fighting the Korean War. In 1949, the Soviet Union had tested its first fission weapon and then in August 1953, its first thermonuclear device.

Lawrence Livermore had been founded only one year earlier as the nation's second nuclear weapons laboratory. The Laboratory's primary mission was to contribute to U.S. efforts to deter Soviet aggression by more rapidly advancing nuclear weapons science and technology. The nation's strategic goal was to develop a nuclear arsenal capable of deterring any nuclear attack—which to many people during that time seemed imminent. Livermore contributed to this mission by developing the submarine-launched ballistic missile warhead, which removed a first-strike capability as a strategic military option. For the remainder of the Cold War, the U.S. and its allies relied on the nuclear weapons developed at Lawrence Livermore and Los Alamos national laboratories. And deterrence worked—no nuclear weapons were used during the Cold War.

In addition to this success, Livermore researchers began to find civilian uses for the weapons technologies they developed. Many of these products and processes—unimagined in 1953—continue to benefit society today.

Project Plowshare and Beyond

One of the nation's earliest and most ambitious efforts to develop civilian applications of nuclear technology was Project Plowshare, which was established by the U.S. Atomic Energy Commission and Congress in 1957. Plowshare research included studies to determine whether nuclear explosives could be safely and expediently used to make harbors, canals, and dams; stimulate natural gas reservoirs; or process underground oil shale into oil. Project Plowshare was terminated in 1977, primarily because of the public's concern about the project's environmental consequences. Nevertheless, its legacy remains in many Livermore efforts—most notably in the expertise developed in atmospheric and earth sciences.

For example, in the 1970s and 1980s, Livermore pursued efforts to develop an underground coal-gasification process that converted coal beds into natural gas without mining. This method had two benefits: it reached coal that, for economic reasons, could not be accessed with surface mining techniques; and it produced a combustible gas that was easy to clean. In another Plowshare offshoot, Laboratory scientists investigated the use of nuclear explosives—and later high explosives—to fracture oil shale and liberate the oil it contained. From that research, they developed sophisticated surface-retorting techniques for converting the kerogen in shale into oil as well as the computer models to predict the natural production of oil from kerogen, which have been adopted by major oil companies worldwide.

Through these Plowshare projects, the Laboratory began to build its technology base in geosciences. As a result, Livermore has made significant contributions to ongoing studies of a proposed high-level nuclear waste repository at Yucca Mountain, Nevada. For more than 25 years, Laboratory scientists and engineers have combined their expertise in nuclear materials, geologic science, and computer modeling to help develop safe and secure methods for storing the radioactive wastes produced by nuclear power plants.

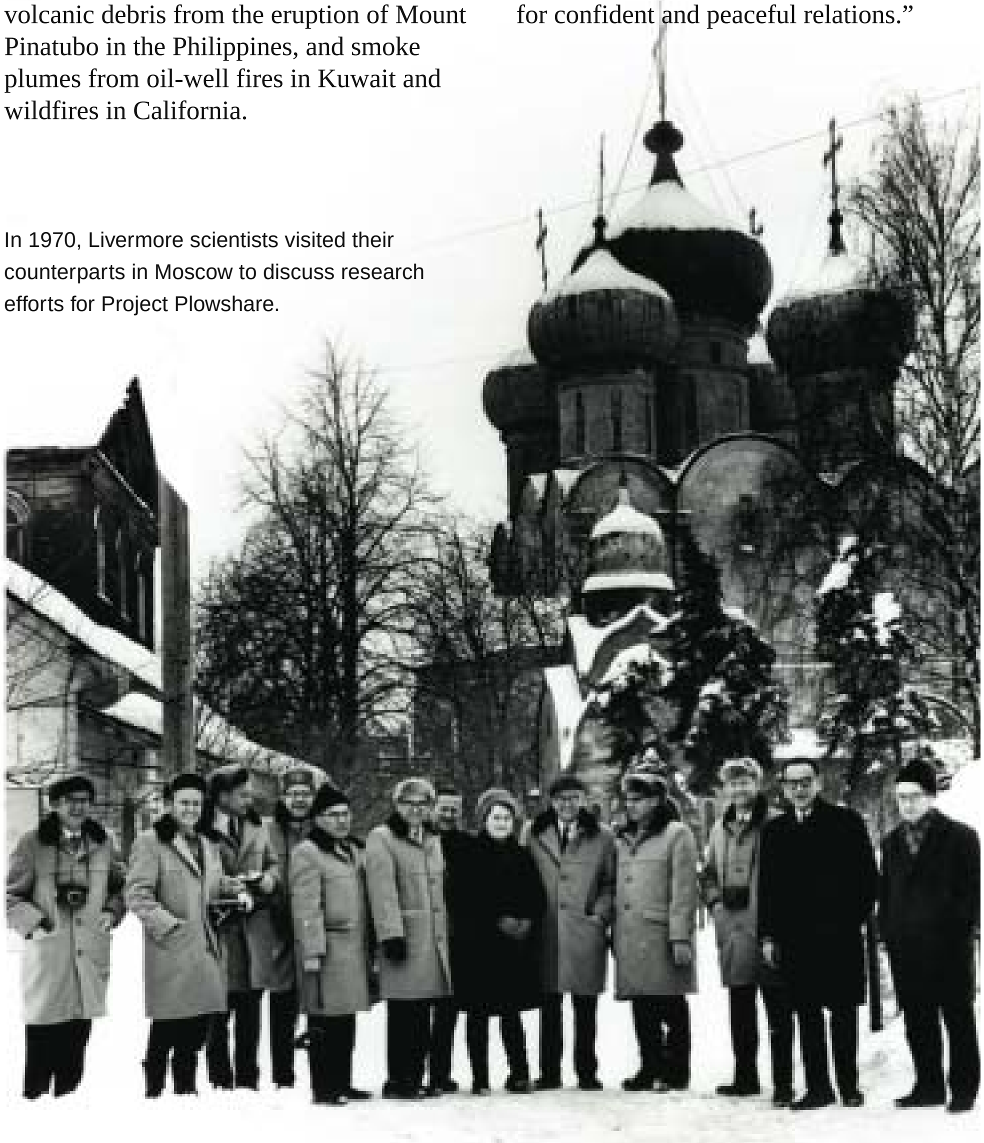
The Plowshare projects also expanded the Laboratory's efforts to understand nuclear fallout. Building on this expertise,

In 1953, President Dwight D. Eisenhower addressed the United Nations General Assembly. His speech, Atoms for Peace, called on all world leaders to move toward peaceful uses of nuclear technology. (Photograph courtesy of the United Nations/DPI Photo.)

Livermore developed the Atmospheric Release Advisory Capability (ARAC) as an emergency response service for the federal government. ARAC's original mission was to estimate the fate of radionuclides in the event of actual or potential radioactive releases. In 1979, the National Atmospheric Release Advisory Center (NARAC) at Livermore opened ahead of schedule in response to the nuclear power plant emergency at Three Mile Island in Pennsylvania. Since then, NARAC has provided emergency-response assistance by tracking airborne releases from the Chernobyl nuclear power plant, volcanic debris from the eruption of Mount Pinatubo in the Philippines, and smoke plumes from oil-well fires in Kuwait and wildfires in California.

Cooperating with the Soviets

In the 1950s, a chief concern for world leaders was the growing tension between the dominant political philosophies symbolized by the U.S. and the Soviet Union. President Eisenhower recognized that the two nuclear powers had to work together to diffuse a potential conflict. In his Atoms for Peace speech, he thus proposed modest steps to "initiate a relationship with the Soviet Union which will eventually bring about a free intermingling of the peoples of the east and of the west—the one sure, human way of developing the understanding required for confident and peaceful relations."



In 1970, Livermore scientists visited their counterparts in Moscow to discuss research efforts for Project Plowshare.

Magnetic fusion energy was the first research area in which U.S. and Soviet nuclear scientists cooperated. Livermore scientists had already been working in this area even before Eisenhower's speech. Afterward, they began to collaborate with Soviet, British, and other American scientists to study controlled fusion reactions as a method for power generation. Results from that research were presented at the 1958 Atoms for Peace Conference in Geneva.

The Cold War lasted another 30 years, but more areas of cooperation opened up. The two superpowers negotiated new treaties that limited nuclear testing and reduced their nuclear arsenals. To ensure that the treaties could be enforced, government agencies called on Livermore and Los Alamos scientists to provide technical support during the negotiations.

The Laboratory also began to research methods for monitoring nuclear explosions. From those efforts, which began in the Vela Program, scientists developed technologies to detect nuclear explosions whether they were detonated at the Earth's surface, underground, in space, or at high altitude. Nuclear explosion monitoring remains an important research activity at the Laboratory. Current efforts entail developing databases, methodologies, algorithms, software, and hardware to improve monitoring capabilities around the world. Technical support of arms-control negotiations also continues to be an integral part of Livermore's overall mission. Today, experts at the Laboratory provide technical assistance to the Department of Energy (DOE) and its National Nuclear Security Administration (NNSA) on treaty verification, and they analyze technical issues associated with nuclear arms-control measures.

A turning point in U.S.–Soviet relations came in 1988 with the Joint Verification Experiment (JVE). For the JVE, each nation agreed to allow the other to take verification measurements, including hydrodynamic yield, during one nuclear experiment conducted at each host country's nuclear test site. A U.S.–Soviet collaboration involving nuclear experiments was unprecedented and showed how far the two nations had come in working together.

The first JVE event, Kearsarge, was conducted on August 17, 1988, at the Nevada Test Site (NTS). Soviet scientists who were escorted to NTS not only observed U.S. scientists and engineers preparing for an underground nuclear experiment but also recorded measurements during the event. Then on September 14, the Shagan Event was conducted at the Soviet Union's Semipalatinsk Test Site. As with the Kearsarge Event, U.S. scientists observed the operations and recorded measurements.

The measurement technique used for the JVE, called CORRTEX, was developed at Los Alamos using concepts that originated at Livermore. This technique measures the speed of the shock wave produced by a nuclear explosion and then correlates that speed to the nuclear yield produced in the explosion.

"The JVE was an extraordinary success," says Bob Schock, a U.S. participant in the JVE who now is a CGSR senior fellow and director of the center's Atoms for Peace project. "Professional relationships were formed among Livermore and Russian scientists that remain strong today. It marked the beginning of the end of the Cold War."

Treaties Call for Better Detectors

In 1953, President Eisenhower foresaw that "the knowledge now possessed by several nations will eventually be shared by others, possibly all others." In response to this potential threat, he recommended that the U.S. accelerate its efforts to develop nuclear detection systems. Since then, the Laboratory has developed an array of radiation detection systems to support various arms-control treaties. One such treaty, the 1987 Intermediate-Range Nuclear Forces Treaty, allowed the U.S.

A simulation of smoke dispersion from a fire at a tire disposal pit in Tracy, California, is superimposed on an aerial photograph taken a few hours after the fire started.

U.S. and Soviet flags fly side by side atop the experiment tower at the Nevada Test Site during the first of two Joint Verification Experiments in 1988.

Trains leaving and entering Astrakhan on the Caspian Sea are monitored for nuclear materials as they pass between radiation detectors.

and the Soviet Union to measure radiation from the other nation's nuclear warheads.

To develop more accurate diagnostic equipment for this treaty, Livermore opened the Radiation Measurement Facility (RMF) in 1988. The RMF has hosted several international experiments, including a demonstration in 1997 of potential technologies to verify the Trilateral Initiative. Formed in 1996, the Trilateral Initiative is a collaboration of Russia, the U.S., and the International Atomic Energy Agency (IAEA) to ensure that fissile material removed from dismantled warheads not be reused for weapons. (IAEA was established in 1957 as the world's Atoms for Peace organization under the United Nations and is responsible for verifying that nations comply with their nonproliferation agreements.)

Such radiation measurements, which are taken to verify that a country complies with an arms-control treaty, can be intrusive and can reveal aspects of a nuclear weapon's design—details that are among the most closely guarded secrets of nuclear weapons states. To help protect this information, Livermore scientists designed two systems that measure radiation without revealing warhead designs. The first system, called the template-matching method, compares the radiation signature from an inspected item with a known standard for a weapon or component of the same type. The second system, called the attribute measurement method, characterizes an inspected item to determine whether the item possesses one or more of the attributes of nuclear weapons and their components.

Another area of Livermore detector research is aimed at surmounting the difficulties encountered when fissile materials are shielded, as they are in nuclear warheads. Many detectors are designed to operate in passive mode, collecting air samples and characterizing background radiation to determine whether the telltale gamma rays emitted by fissile materials are present. To detect shielded materials, Livermore scientists are working on active detection techniques. These techniques induce radiation, for example, by bombarding a shielded container with neutrons or energetic photons. Samples are then analyzed to determine whether they contain highly enriched uranium (HEU). This technology also may be useful for homeland security. It is being adapted for use at ports and customs inspections, where investigators need improved tools to prevent the clandestine smuggling of nuclear material.

Other Livermore-designed detectors are being used in a U.S.–Russian project to ensure that HEU from dismantled nuclear

Where Scientists and Policy Makers Meet

The Center for Global Security Research (CGSR) at Lawrence Livermore brings together international experts in science, technology, national security, and policy to explore the ways in which science and technology intersect with policy development. Such interactions help both scientists and policy makers understand these issues so they can work toward common goals. "Think tanks abound," says Eileen Vergino, the center's deputy director, "but few of them have Livermore's concentration of experts in nuclear weapons, laser, biotechnology, energy, and other related fields."

To foster in-depth discussion of common issues and goals, CGSR sponsors workshops, research fellowships, and independent analyses, which have included participants from the past and current U.S. Administrations, Congress, and the Departments of Defense, Energy, and State as well as their international counterparts. For example, past workshops have focused on security and the technology-driven threats to the U.S. and its allies and on deterrence in response to new threat scenarios.

In November 2003, CGSR held a two-day symposium entitled, "Atoms for Peace after 50 Years: New Challenges and Opportunities." This symposium concluded a series of workshops at which scientists and policy makers discussed the progress made toward goals President Dwight D. Eisenhower outlined in his Atoms for Peace speech, which he delivered to the United Nations General Assembly in 1953. "In our spring 2003 workshops, we asked participants to examine both the benefits and risks of nuclear technology—whether it is used for national security or civilian applications," says Vergino. Participants were also encouraged to discuss the crosscutting issues, such as nuclear waste and disposition, environmental protection, regulations, management of nuclear systems, and most importantly, public confidence in the safety and reliability of these technologies.

Speakers at the symposium included Paul Longsworth, deputy administrator for the National Nuclear Security Administration, and Susan Eisenhower, granddaughter of the late President Eisenhower and chairperson of the Eisenhower Institute. In her presentation, Eisenhower said, "The genie is already out of the bottle," and she encouraged attendees to search for synergetic uses of nuclear technology that provide national security and civilian benefits. CGSR's final report is available online at cgsr.llnl.gov.

warheads is blended down to low-enriched uranium, which can be used to power commercial nuclear reactors. Livermore is also exploring a concept for detectors that can verify the origin of weapons-grade plutonium.

New Challenges after the Cold War

When the Cold War ended, a major international concern was the status of nuclear materials and weapons from the former Soviet Union. The U.S. has worked with Russia to ensure that weapons-grade nuclear materials do not get into the wrong hands. Livermore-designed detection systems are now located at some of the most important nuclear institutes in Russia, such as the All-Russian Scientific Research Institute of Technical Physics in Snezhinsk, a facility similar to Lawrence Livermore. Another program is helping customs officials in Russia to install nuclear detection equipment across that nation's 20,000 kilometers of borders. A U.S.–Russian team has equipped Moscow's Sheremetyvo International Airport with radiation detection equipment, including pedestrian portals to monitor departing passengers. Similar pedestrian- and vehicle-monitoring portals have been set up at border sites (see the figure on p. 8).

Both the U.S. and Russia are committed to reducing their nuclear arsenals. In the early 1990s, these efforts were given additional impetus when the Nuclear Non-Proliferation Treaty (NPT) was about to expire. The NPT called for signatory nations without nuclear weapons to forgo acquiring them. In exchange, these nations would have access to peaceful applications of nuclear technologies. Meanwhile, nations with nuclear weapons agreed not to share their weapons technology with others and to pursue negotiations in good faith to end the nuclear arms race at the earliest possible date. In negotiations to extend the NPT, the nonnuclear signatory nations wanted the five nuclear signatories—the U.S., Russia, United Kingdom, France, and China—to demonstrate more visible progress toward nuclear disarmament. The five nations eventually agreed to cease nuclear testing, and in 1995, the NPT was extended indefinitely.

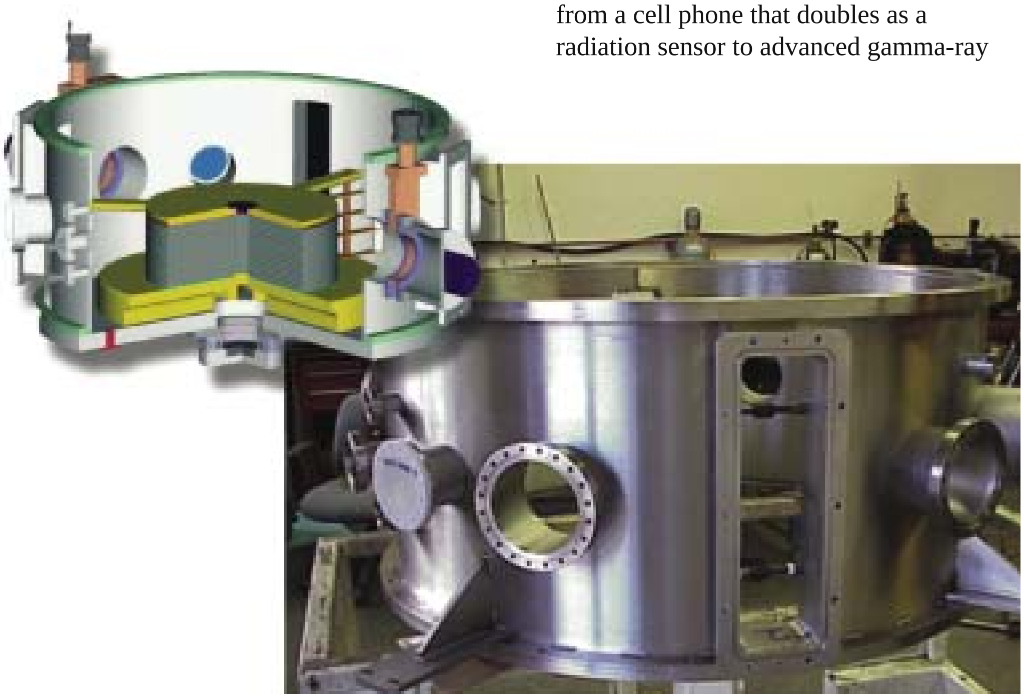
In the absence of nuclear testing, the nation needed another approach to ensure the safety and reliability of its nuclear deterrent. As a result, in 1996, DOE established the Stockpile Stewardship Program, to provide the tools and technologies scientists need to better understand the physical interactions involved in nuclear weapons and how component aging might affect weapon reliability. The challenge of stockpile stewardship has led to recent advances in many research areas at the Laboratory, including physics, chemistry, materials science, and engineering.

For example, DOE launched the Accelerated Strategic Computing Initiative (ASCI) to develop the high-performance computers and advanced software needed to simulate weapon performance more accurately. Now called the Advanced Simulation and Computing Program, ASCI places the NNSA laboratories at the forefront of scientific computing. Lawrence Livermore is now home to ASCI White, a supercomputer that can process 12.3 trillion operations per second (teraops). The Laboratory is also preparing for the delivery of ASCI Purple, which will be capable of up to 100 teraops. Novel computer architectures with still greater capabilities are being developed. (See *S&TR*, June 2003, pp. 4–13.)

The Adaptable Radiation Area Monitor (ARAM), a portable radiation monitoring system, can detect small amounts of radioactive materials from a distance.

Terascale computing offers the potential to revolutionize scientific discovery. It can lead to unprecedented levels of understanding in many areas of physics, including climate and weather modeling, environmental studies, and the design of new materials.

Another cornerstone of the Stockpile Stewardship Program is the National Ignition Facility (NIF). (See *S&TR*, September 2003, pp. 4–14.) In December 2002, NIF achieved "first light" when its first four laser beams were activated. Then in May 2003, the project set a world record for laser performance when NIF produced 10.4 kilojoules of ultraviolet laser light. When this 192-beam laser facility is fully operational, it will generate 1.8 megajoules of ultraviolet light. With NIF's unique capabilities, scientists can explore the world of high-energy-density physics, delving into the inner workings of nuclear weapons, astrophysical phenomena, and materials under extreme conditions.



Livermore is addressing the feasibility of a small proton therapy accelerator—a device for radiation treatment that can more accurately target cancer tumors without harming healthy tissue.

Detectors for Homeland Security

With the increased number of terrorism incidents worldwide, the U.S. government needs new tools for improving homeland security, and Livermore scientists and engineers have responded to that call. In April 2003, Livermore opened the Radiation Detection Center, which coordinates more than a dozen projects for detecting clandestine nuclear materials. The center's research involves more than 200 Laboratory employees from eight directorates and Livermore's Homeland Security Organization.

Laboratory physicist Ken Sale says, "We are adapting tools originally used for weapons testing to solve homeland security problems. Many of the constraints we have are the same, but the environments are different." For example, detection systems for homeland security must address the possibility that weapons of mass destruction or weapons materials could be brought into the U.S. inside maritime cargo containers or driven across U.S. borders.

The detectors being developed range from a cell phone that doubles as a radiation sensor to advanced gamma-ray spectrometers. One Livermore system stores a radiation detector on buoys placed at the entrance of marinas, ports, and waterways. (See *S&TR*, January/February 2004, pp. 19–22.) Researchers have also developed handheld, electromechanically cooled germanium detectors, such as RadScout and CryoFree/25. (See *S&TR*, September 2003, pp. 2 and 24.) Both of these detectors achieve precisions previously found only in a laboratory and do not require heavy, bulky equipment to cool the germanium.

More recently, scientists unveiled the Adaptable Radiation Area Monitor (ARAM) for homeland security (see the figure on p. 9). ARAM is a portable system that can detect small amounts of radioactive materials from a distance. When radioactive material is detected, ARAM photographs the area, collects high-resolution spectral data for analysis, and rapidly sends the information to a first responder. Another system being developed uses a network of correlated radiation detectors and cameras to locate and track radioactive or nuclear material in vehicles moving at high speeds. Researchers are also measuring the physical properties of nuclear materials so they can improve the fidelity of the computer calculations used to model detector designs.

Although the primary use of these technologies will be to locate nuclear materials and protect against acts of terrorism, they also can be used to verify compliance with arms-control agreements and to improve diagnostics for NIF, environmental monitoring, astrophysics, and medical applications.

Advanced Medical Technologies

Livermore's expertise in nuclear technology has helped scientists understand the potential health risks of human exposure to chemicals and radiation. Livermore began its biomedical research in 1963, in an effort to measure an individual's exposure to radiation. This research area continued to grow and is now a Laboratory directorate, Biology and Biotechnology Research Programs (BBRP). BBRP has made significant advances in the study of human radiation biology and biotechnology. BBRP research has aided organizations such as the Radiation Effects Research Foundation (RERF), which monitors the health of people from Hiroshima and Nagasaki who survived the atom bombs dropped on those cities in August 1945. The RERF study—possibly the largest study ever undertaken in human epidemiology—has given the world a realistic assessment of radiation risk.

Livermore researchers have developed several biological dosimeters, or biodosimeters, to detect and measure changes in human cells from ionizing radiation. The glycophorin-A (GPA) human mutation assay can measure subtle distinctions between normal and mutant red blood cells. After the 1986 Chernobyl nuclear accident, the GPA assay was used to screen cleanup workers for exposure. (See *S&TR*, September 1999, pp. 12–15.) It is now used extensively to study genetic damage in human populations that have been exposed to potentially mutagenic agents.

Another biodosimeter, chromosome painting, is used to fluorescently label small pieces of DNA. Laboratory scientists first developed this process to identify reciprocal translocation—one of the distinguishing effects of radiation damage to DNA. In reciprocal translocation, the ends of two chromosomes break off and trade places with each other. With chromosome painting, scientists see and count translocations between two differently painted chromosomes and thus determine a person's likely prior exposure to ionizing radiation.

Much of BBRP's research focuses on better understanding how different doses of radiation affect human cells. One project is studying the cellular effects from exposure to low doses of radiation, such as those received from medical procedures or in certain occupational areas. (See *S&TR*, July/August 2003, pp. 12–19.) Another project recently demonstrated that cells exposed to low-level ionizing radiation will activate genes that specialize in repairing damaged chromosomes, membranes, and proteins and thus counter cellular stress. Livermore scientists also found an adaptive response in human cells, whereby a cell that is pretreated with a tiny dose of ionizing radiation will better withstand a later, much higher dose, and they identified cellular changes that occur in the mammalian brain after low-dose radiation exposure. The results from all of these studies have useful applications, for example, in setting exposure limits for employees at radioactive waste cleanup areas and for people undergoing various medical procedures.

One notable innovation in biotechnology research at Livermore comes from adapting weapons technology to a civilian application. PEREGRINE, a treatment-planning program for radiation beam therapy, couples Livermore's storehouse of radiation transport data with powerful simulation tools and desktop computers. It can be used to diagnose cancers and treat tumors that have metastasized. (See *S&TR*, May 1997, pp. 4–11; April 2001, pp.15–17.) Another cancer-treatment system, called MINERVA, allows physicians to track targeted molecular radionuclides and determine exactly where a drug is distributed in the body. (See *S&TR*, July/August 2003, pp. 4–11.)

Technologies being developed for underground subcritical tests at NTS may also lead to a compact proton accelerator for radiotherapy treatment of deep-seated tumors. One design breakthrough is a dielectric wall accelerator being developed for the NTS x-ray source. This dielectric wall can handle the high electric field stresses generated by the 250-megavolt machines used for radiotherapy. Livermore researchers have already tested a millimeters-thick dielectric wall sample, which withstood an electric field of 100 megavolts per meter. They are now exploring this technology for use in a proton accelerator only 3 meters long. (See the figure on p. 10.) If successful, this technology would allow an oncologist to target radiation more directly to a cancer tumor while avoiding healthy tissue.

Maintaining the Legacy for Peace

Fifty years after President Eisenhower's landmark speech, the world is vastly different, but the challenge he identified remains—managing the risks of nuclear technology while obtaining its benefits. With its recent focus on Atoms for Peace, CGSR has helped to examine the gap between the scientists who are developing nuclear technologies and the policy makers who must safeguard them. By working together, these two communities contribute to Eisenhower's legacy, which continues a Laboratory tradition—providing innovative technologies to enhance national security and meet other enduring national needs.

—Gabriele Rennie

Key Words: Adaptable Radiation Area Monitor (ARAM), Advanced Simulation and Computing (ASCI) Program, Atoms for Peace, biodosimetry, Center for Global Security Research (CGSR), Joint Verification Experiment (JVE), National Atmospheric Release Advisory Center (NARAC), Project Plowshare, proton therapy, Radiation Detection Center, Radiation Measurement Facility (RMF).

For further information contact Eileen Vergino (925) 422-3907 (verginoes@llnl.gov).

President Eisenhower's Atoms for Peace speech is available at: www.eisenhower.utexas.edu/atoms.htm.

CGSR's report on the 2003 Futures Roundtable is available at: cgsr.llnl.gov.